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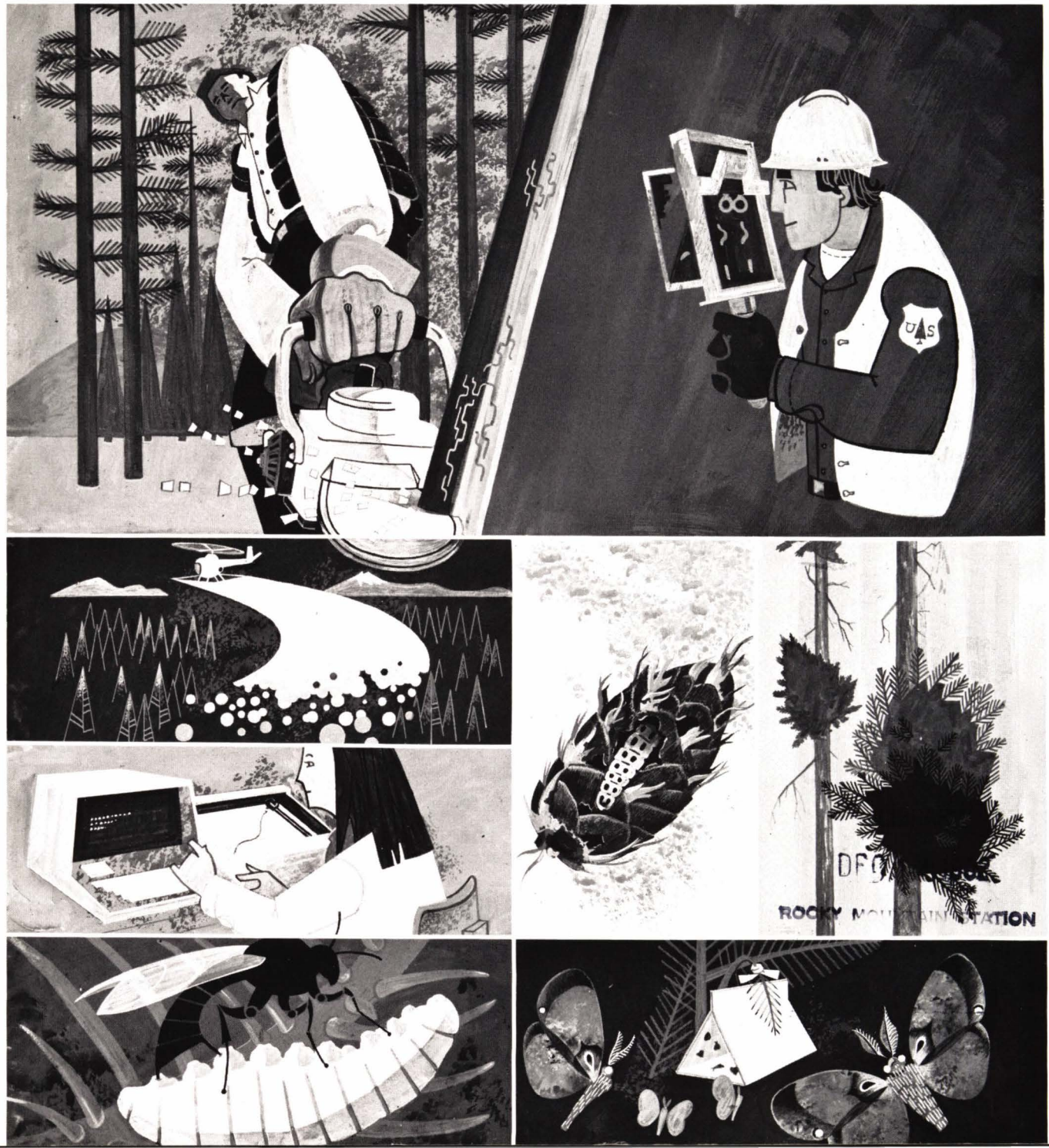
PANORAMIC AERIAL PHOTOGRAPHY FOR MAPPING GYPSY MOTH DEFOLIATION



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PANORAMIC AERIAL PHOTOGRAPHY FOR MAPPING GYPSY MOTH DEFOLIATION

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ABSTRACT

Defoliation by gypsy moth, Lymantria dispar L., was mapped from high altitude panoramic color IR photography over a 2800 mi² test site in central Pennsylvania. Defoliation could be readily discerned and mapped when experienced photointerpreters familiar with mapping vegetation damage did the classification. Mapping accuracy is dependent upon timely photo acquisition. Cost of panoramic aerial photography is 1.7 times that of aerial sketchmapping but only one-third the cost of conventional nine-inch aerial photography. Therefore, if accurate mapping of infestation boundaries and a permanent record of defoliation is required, panoramic aerial photography is a cost effective alternative for data acquisition.

INTRODUCTION

The gypsy moth, Lymantria dispar L., is a hardwood defoliating insect that was introduced into North America from Europe. From an initial introduction in 1869 in Massachusettes, it has expanded its range to encompass vast areas of hardwood forests in the Northeast with isolated infestations having appeared throughout much of the United States. During 1981, approximately 12.9 million acres in the New England states, New York, New Jersey, Pennsylvania and Maryland experienced varying degrees of damage (USDA 1982).

The insect feeds on over 300 species of plants including hardwood shrubs and trees and conifers. It prefers oaks, Quercus spp., particularly members of the white oak group.

In recent years, gypsy moth has attracted considerable public attention because of the extensive damage caused by feeding larvae and the controversies associated with direct control by aerial and ground spraying of chemical insecticides. Direct control efforts have been concentrated in urban and forested communities and developed recreation sites within some of the most densely populated regions of the United States.

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The extent and intensity of defoliation is mapped annually within the general area of infestation in the Northeast. This is usually done by personnel from state forestry agencies using small aircraft and aerial sketchmap techniques. These data monitor the spread and status of infestations and identify sites which might be considered for direct control the following season.

Aerial sketchmapping is an effective means of rapid data acquisition over extensive areas of forest at relatively low cost. However, accuracy of resultant data is dependent upon observer experience, ability and fatigue. Therefore, it is subject to uncontrolled error. Large or medium scale (< 1:15,840) nine-inch format color and color IR aerial photographs, on the other hand, provide considerably greater mapping accuracy. Acquisition costs of photography at these scales is high, and is usually prohibitive for continuous area coverage for a single purpose mapping application such as vegetation damage. This approach is generally considered only cost-effective when the attribute being mapped can be sampled, such as tree mortality caused by coniferous bark beetles (Ciesla, et al. 1967, Klein et al. 1979, and Wert and Roettgering 1968).

Recent testing and evaluation of aerial photos taken with an optical bar panoramic camera shows that high resolution images capable of resolving vegetation damage can be obtained from high altitudes (ca. 65,000 ft. above mean sea level). These camera systems, mounted in reconnaissance aircraft, are capable of covering large areas of land rapidly and can acquire continuous photo coverage over entire outbreak areas (Ciesla et al. 1982, Klein 1982, Dillman and White 1982, Caylor et al. 1982). Characteristics and geometry of this system and resultant images are described by Liston (1982). This report summarizes results of an evaluation of panoramic aerial photography for mapping defoliation by gypsy moth.

METHODS

Description of Test Site

A rectangular area encompassing approximately 2800 mi^2 in central Pennsylvania was selected for a test site. The area included portions of Centre, Clinton, Cumberland, Franklin, Huntingdon, Juniata, Mifflin, Perry, Snyder and Union Counties and contained a significant area of hardwood forests suffering feeding damage (Fig. 1).

Geologically, the test site emcompasses portions of two physiographic provinces of the Appalachian mountain system; the Valley and Ridge and the Allegheny Plateau. The Valley and Ridge province consists of sedimentary formations moderately to strongly folded and faulted into a series of long narrow parallel ridges and broad intermontaine valleys oriented in a northeast-southwest direction. Elevations range from 450 feet above sea level in the valley bottoms to ca. 2,400 feet on the crests of the highest ridges. The ridges are heavily forested and the valleys have been cleared for agriculture. However, fields and pastures are interspersed with small woodlots. The Allegheny Plateau province is a high dissected broad topped plateau consisting of a gentle rolling surface cut by dendritic stream

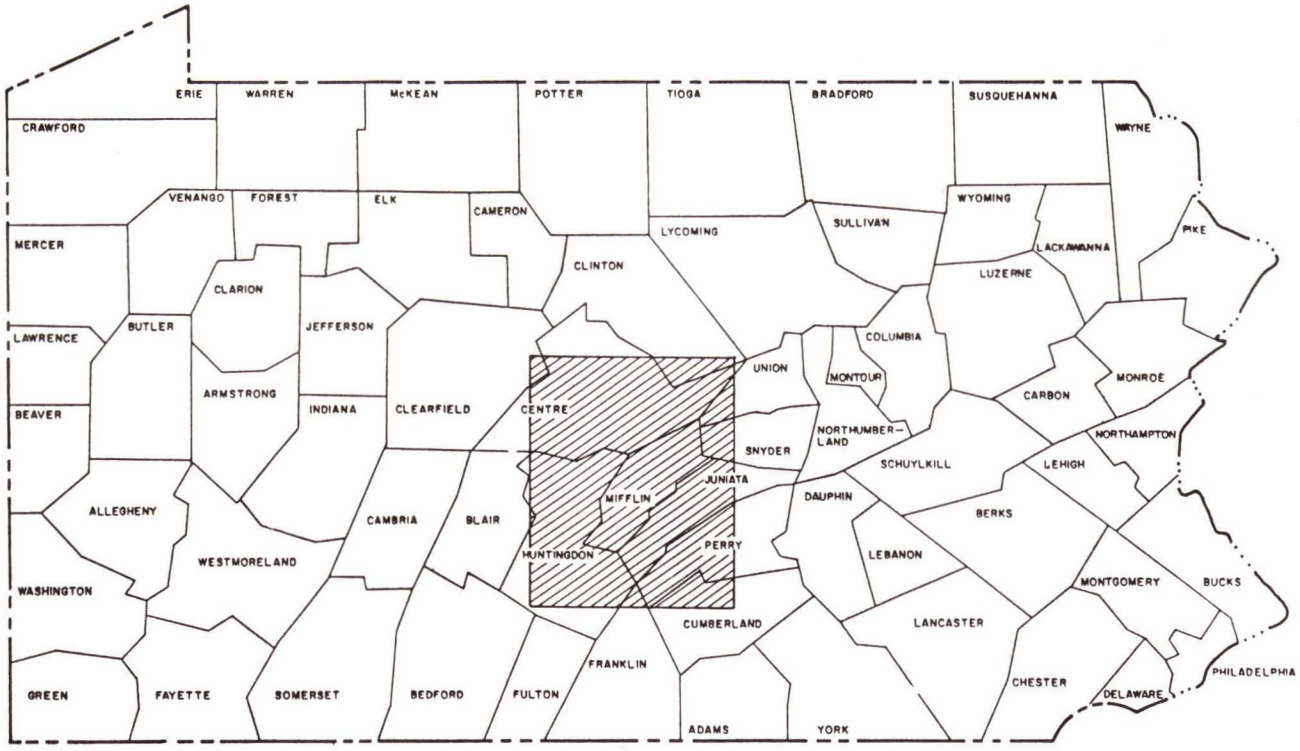


Fig. 1 - Location of 1981 gypsy moth panoramic aerial photography test site (Shaded Area).

patterns. The stream valleys are v-shaped with steep sides and narrow valley floors. This province is heavily forested except where cleared for farming and where strip mining has extracted bituminous coal.

Forest cover type in the test site is almost exclusively mixed hardwoods consisting of several species of oaks, hickories, Carya spp., maples, Acer spp., yellow poplar, Liriodendron tulipifera and other species. Occasional forest plantings of pines, Pinus spp., and other conifers occur in the valley bottoms. The gypsy moth began to cause noticeable defoliation in this area during the early 1970's. In addition to gypsy moth, a number of native hardwood defoliators are indigenous to the region and occasionally reach epidemic levels causing damage that, from a distance, appears identical to that caused by gypsy moth. These include the linden looper, Erannis tiliaria (Harr.), fall cankerworm, Alsophila pometaria (Harr.), spring cankerworm, Paleacrita vernata (Peck), forest tent caterpillar, Malacosoma disstria Hbn., oak leaf tier, Croesia semipurpurana (Kearfott), oak leaf roller, Archips semifuranus Wlkr., saddled prominent, Heterocampa guttivitta (Wlkr.) and others.

Photographic Parameters

Photos were taken on June 18, 1981. The flight plan specified two north-south flight lines spaced at a mean distance of 22.5 statute miles. Each flight line was approximately 76 miles long.

A third generation panoramic camera system was used for the test; the Itek IRIS-II.[2/] This test was the first time the IRIS-II was deployed for a vegetation damage mapping application. Characteristics of the IRIS II are similar to the KA-80-A except that the normal field of view is for the IRIS II 140° instead of 120° and resolution has been significantly improved through structural changes in the camera, use of a new rigidized pallet system in the aircraft and introduction of an advanced design optical window.

Aerial platform was a U-2 flying at ca. 65,000 feet above mean sea level. Expected nadir scale was, therefore, ca. 1:31,000. Film used was Kodak High Definition Aerochrome Infrared (SO-131), a slow speed, high resolution color IR reversal film.

Photo Interpretation

Principle point of each photo was marked and located on 1:63,360 (inch = 1 mile) scale Pennsylvania Department of Transportion County highway maps. Forested areas were classified into the three classes used by the Pennsylvania Bureau of Forestry when conducting aerial sketchmap surveys for gypsy moth:

1 - No aerially visible defoliation

4 - Moderate and Widespread - pure host type with first noticeable defoliation visible from aerial observation (generally 30-60% defoliation)

6 - Heavy and Widespread - pure host type with total loss of host foliage (generally >60% defoliation)

Fig. 2 - Photo interpreter classifying gypsy moth defoliation and location of defoliated areas to map base.

2 Mention of commercial products is for convenience only and does not imply endorsement by USDA Forest Service or its cooperators.

A team of three photo interpreters working individually examined every other photo frame monoscopically on a 1 ft. x 2 ft. portable light table (Fig. 2). Each interpreter classified approximately 25 frames. Only that portion of the photo that fell within ± 40° of nadir was classified. Areas of defoliation were classified into category 4 or 6 and sketchmapped as polygons of infestations onto 1:24,000 scale USGS 7 1/2 minute quadrangle maps. These could then be directly compared to the maps currently produced by operational aerial sketchmap surveys.

Comparison with Existing Data

The existing operational data base consisted of a series of USGS 7 1/2 minute quadrangles showing location of defoliated areas mapped independently by the Pennsylvania Bureau of Forestry aerial survey teams.

Sketchmap and aerial photo classifications were compared on a grid cell basis using the Pennsylvania Forest Pest Locator Grid, a geographic information system under development by the Pennsylvania Bureau of Forestry. This system subdivides each USGS topographic map into 225, 160 acre cells. Each cell was classified according to which damage category covered most of the land area within the cell as determined by sketchmapping and photo interpretation. Those cells containing > 50% non-forest were discarded from the data base.

Resultant data was summarized in a series of 3x3 error matrices. These were for the entire data base, cells occurring within ± 20° of nadir, and ± 20° - ± 40° of nadir, and for each photo interpreter. The measure of agreement K and its approximate large sample variance (s^2) was computed for each error matrix in accordance with procedures described by Bishop et al. (1975, pp. 395-397).

Significant differences between error matrices were tested for using a procedure recently developed and reported by Congalton et al. (1982) and is as follows:

$$z = \frac{K_1 - K_2}{\sqrt{s_1^2 + s_2^2}}$$

where: K_1, K_2 = K for each error matrix,

s_1^2, s_2^2 = large sample variance of each K,

and $H_o: K_1 = K_2$ rejected in favor of $H_1: K_1 \neq K_2$,

if $z \geq 1.96$ ($p = .05$) or 2.58 ($p = .01$) and is normally distributed.

RESULTS

Photo Quality

Flight line spacing resulted in a holiday of missing photo coverage which averaged six statute miles through the center of the test site (Fig. 3) when only that portion of the photo frame ± 40° of nadir was used for photo interpretation. Mean nadir photo scale was 1:32,500.

Photo quality was excellent within ± 40° of nadir. Defoliated areas were easily seen, appearing as tones of gray in marked contrast to the brilliant magenta and red hues of the undamaged hardwood foliage (Fig. 4). Photo interpreters could readily classify foliage conditions into one of the three classes specified by the Pennsylvania Bureau of Forestry. Defoliation was sufficiently conspicuous that a photo interpreter could view the damage monoscopically and easily transfer infestation polygons to the USGS map base.

A shift in color balance toward cyan and a loss of resolution was apparent toward the extremities of each photo frame. This was somewhat visible at 40° of nadir and intensified toward 70° (Fig. 5). This is attributed to combination of atmospheric haze, a frequent phenomenon in mid-summer over the eastern United States, and scan angle with respect to the sun. However, heavy defoliation could be easily discerned even at 70° despite loss of resolution.

Comparison with Aerial Sketchmap Base

An error matrix comparison of 160 acre cells classified by aerial sketchmapping and photo interpretation shows 55.1% agreement over the entire test site [$K = .299$ $s^2 = .000096$ (Table 1)]. Where classification by the two methods did not agree, 37.7% were cases where aerial photo classification was more conservative than sketchmap classification. Assuming that the sketchmap classification is the comparative base, these would be considered omission errors. Only 7.2% of the classifications were commission errors, where aerial photo interpreters classified an area into a more intensive category than did aerial sketchmappers. The greatest single disagreement (17.7%) resulted from areas classified by aerial sketchmappers as "heavy" (class 6) which photo interpreters classified as "moderate" (class 4).

This sizeable error is more the result of timing of data acquisition than photo interpreters' lack of ability to classify defoliation intensity. The aerial photo mission was flown June 18, whereas aerial sketchmap surveys were flown during the period June 24-July 9; 6-21 days later. Larval feeding apparently had not been completed at the time of photo acquisition. Since the greatest volume of foliage is consumed by fifth and sixth instar larvae, a considerable area of additional more intense defoliation would have been seen by the aerial sketchmappers.

Error matrices were developed for photo frame segment (nadir to ± 20° and ± 20° to ± 40°) and photo interpreter (Table 2). Subsequent analysis showed significant differences between photo segments ($p = .01$) with agreement being highest in the nadir to ± 20° segment (Table 3). When these data were partitioned by photo interpreter, only photo interpreter 1 showed a significant difference between photo segments. Closer examination of the data

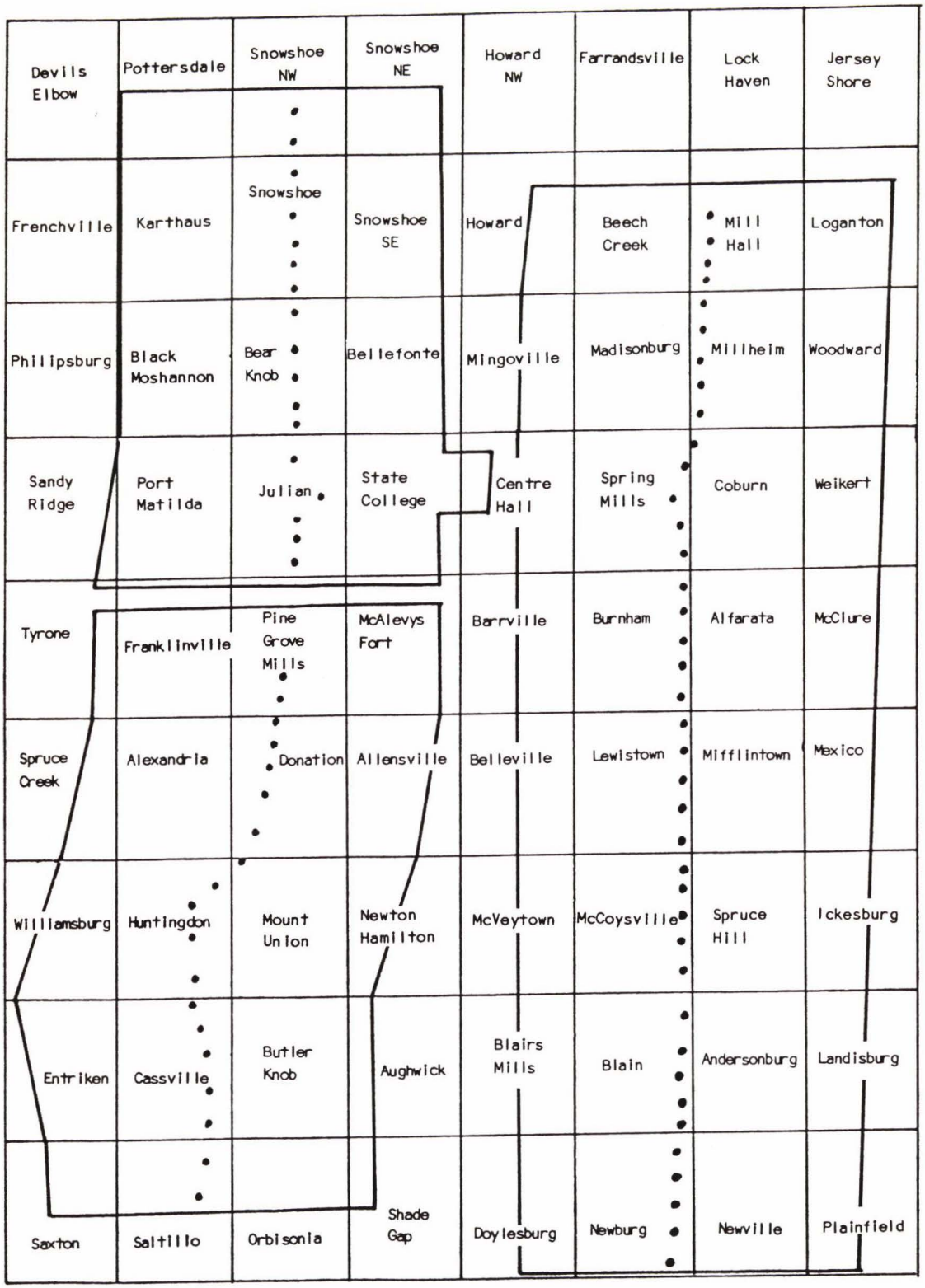
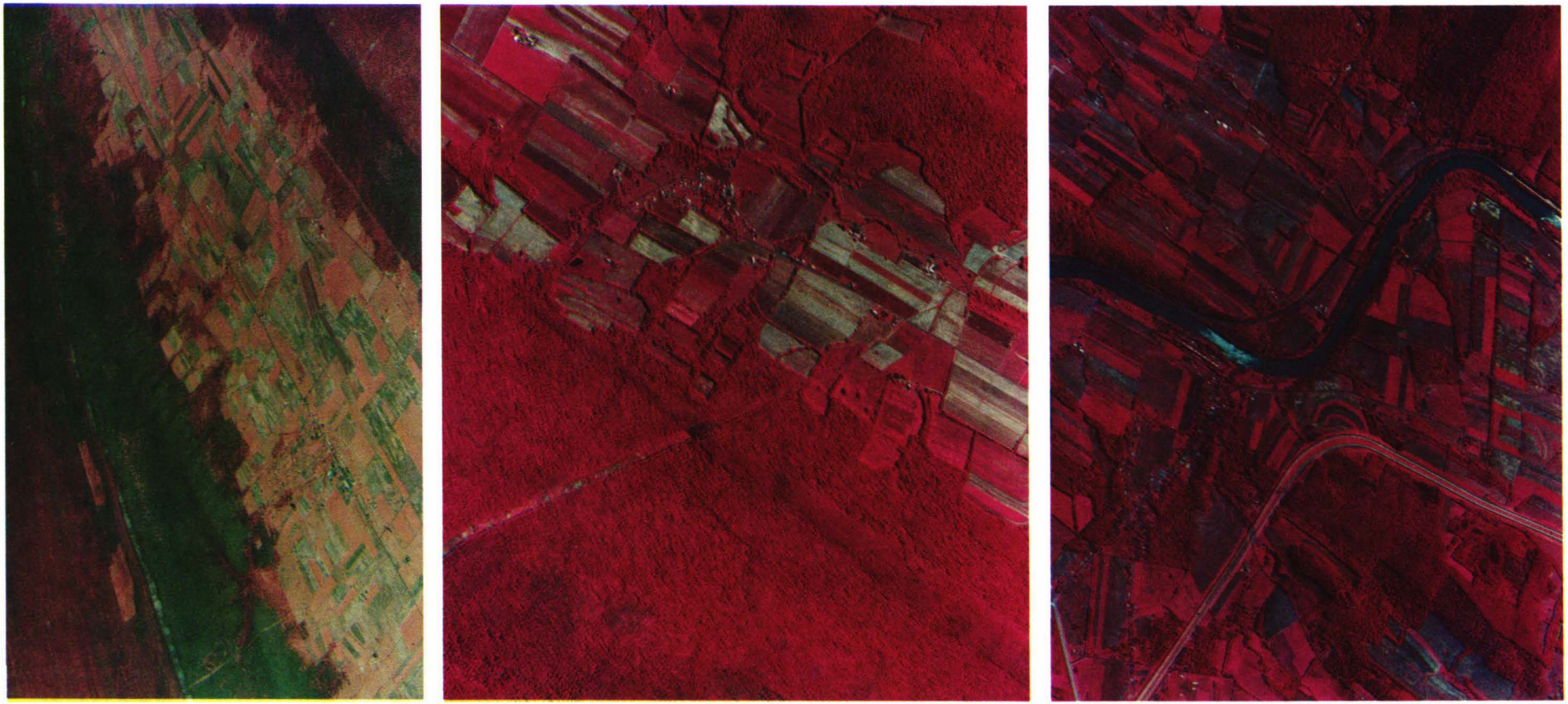


Fig. 3 - U-2 flight pattern and portion of test site for which usable aerial photo coverage (± 40° of nadir) was obtained.

Fig. 4 - Portion of a panoramic aerial photograph of central Pennsylvania showing gypsy moth defoliation and accompanying USGS 7 1/2 topographic map showing defoliation classification by photo interpreters (4 = moderate, 6 = heavy).



< 40°

nadir - ± 10°

20-40°

Fig. 5 - Representative segments of a panoramic aerial photograph of central Pennsylvania showing gypsy moth defoliation

TABLE 1. Error matrix comparing classification of 160 acre cells by aerial sketchmapping and photo interpretation of Gypsy Moth defoliation Central Pennsylvania - 1981

Error Matrix Expressed as Number of 160 Acre Cells

		Aerial Photo Class			
		1	4	6	Total
Sketchmap Class	1	2300	222	92	2614
	4	503	184	126	813
	6	716	1077	868	2661
Total		3519	1483	1086	6088

Error Matrix Expressed as % of 160 Acre Cells

	1	37.8	3.7	1.4	42.9
	4	8.3	3.0	2.1	13.4
	6	11.7	17.7	14.3	43.7
Total		57.8	24.4	17.8	100.0

TABLE 2. Error matrices of aerial sketchmapping vs. photo interpretation of Gypsy Moth defoliation by photo frame segments and photo interpreter, Central Pennsylvania - 1981.

Error Matrix Expressed as Number of 160 Acre Cells

		Nadir to ± 20°				± 20° to ± 40°			
PI Aerial		Aerial Photo Class				Aerial Photo Class			
Sketchmap Class		1	4	6	Total	1	4	6	Total
All Interpreters	1	1633	129	56	1818	667	93	36	796
	4	274	112	72	458	229	72	54	355
	6	467	574	455	1496	249	503	413	1165
	Total	2374	815	583	3772	1145	668	503	2316
1	1	542	26	14	582	242	14	3	259
	4	70	44	9	123	51	10	4	65
	6	95	114	37	246	58	67	99	224
	Total	707	184	60	951	351	91	106	548
2	1	764	43	27	834	74	7	2	83
	4	109	40	53	202	35	19	16	70
	6	157	129	180	466	24	76	114	214
	Total	1030	212	260	1502	133	102	132	367
3	1	90	42	13	145	169	66	28	263
	4	37	22	10	69	54	39	28	121
	6	163	266	228	657	128	332	158	618
	Total	290	330	251	871	351	437	214	1002

Error Matrix Expressed as % of 160 Acre Cells

All Interpreters	1	43.3	3.4	1.5	48.2	28.8	4.0	1.6	34.4
	4	7.3	3.0	1.9	12.2	9.9	3.1	2.3	15.3
	6	12.4	15.2	12.0	39.6	10.8	21.7	1.9	50.3
	Total	63.0	21.6	15.4	100.0	49.4	28.8	21.8	100.0
1	1	57.0	2.7	1.5	61.2	44.1	2.6	0.6	47.3
	4	7.4	4.6	0.9	12.9	9.3	1.8	0.7	11.9
	6	10.0	12.0	3.9	25.9	10.6	12.2	18.0	40.8
	Total	74.4	19.3	6.3	100.0	64.1	16.6	19.3	100.0
2	1	50.9	2.9	1.8	55.6	20.2	1.9	0.5	22.6
	4	7.2	2.7	3.5	13.4	9.5	5.2	4.4	19.1
	6	10.5	8.5	12.0	31.0	6.5	20.7	31.1	58.3
	Total	68.6	14.1	17.3	100.0	36.2	27.9	35.9	100.0
3	1	10.3	4.8	1.5	16.6	16.8	6.6	2.8	26.2
	4	4.3	2.5	1.2	8.1	5.4	3.9	2.8	12.1
	6	18.7	30.5	26.2	75.3	12.8	33.1	15.6	61.7
	Total	33.3	37.8	28.9	100.0	35.0	43.6	21.4	100.0

TABLE 3. Analysis of agreement between aerial sketchmapping and photo interpretation of Gypsy Moth defoliation by panoramic photo frame segment - central Pennsylvania - 1981

Photo Interpreter	Frame Segment	% Agreement	K	s^2	Z
All Interpreters	Nadir to ± 20°	58.3	.316	.00015	2.95**
	± 20° to ± 40°	49.7	.257	.00025	
1	Nadir to ± 20°	65.5	.315	.0006	2.10*
	± 20° to ± 40°	64.1	.399	.0010	
2	Nadir to ± 20°	65.5	.369	.0004	0.76 n.s.
	± 20° to ± 40°	56.4	.335	.0016	
3	Nadir to ± 20°	39.0	.126	.0012	0.065 n.s.
	± 20° to ± 40°	36.5	.123	.0009	

n.s. - $K_1 = K_2$

* - $K_1 \neq K_2$ ($p = .05$)

** - $K_1 \neq K_2$ ($p = .01$)

showed a disproportionately small number of cells classified into the heavy stratum by both photo interpretation and aerial sketchmapping in photo segment nadir to ± 20° for this interpreter. This skewed the marginal totals (Table 2) and caused an inverse relationship between proportion of cells classified correctly and K (Table 3).

Re-examination of the region interpreted by photo interpreter 1 showed that it contained a large proportion of non-forested land and considerable area of non-defoliated forest thus explaining the skewed marginal totals. Therefore, it is questionable if the difference between photo segments is real or an artifact of the proportion of damaged and undamaged forest in the portion of the test site that was interpreted by photo interpreter 1.

Comparison of error matrices by photo interpreter showed no significant differences between photo interpreters 1 and 2 but both were significantly different from photo interpreter 3 (Table 4). This is attributed to experience levels among photo interpreters. Interpreters 1 and 2 had considerable photo interpretation experience and were familiar with the terrain and forest cover types of Pennsylvania (one was a native of New York, the other a native of Ohio). Photo interpreter 3 was a student with some photo interpretation experience but totally unfamiliar with the test site.

Comparison of Costs

Direct cost data for aerial photo acquisition are not available for this test because the photo mission was flown in conjunction with another mission in the Northeastern United States and the photos were obtained at no cost to the Forest Service.

Cost data is available for an operational panoramic aerial photo mission flown over Colorado in 1980 (Dillman et al. 1981). This mission covered 11.2 million acres at a cost of $2.28/mi^2 and was flown by a U-2 based at the NASA Ames Research Center, Moffett Field, California.

Assuming that a NASA U-2 is deployed for a mission in the Northeastern United States from a base on the eastern seaboard and an area of similar magnitude is covered, a reasonable assumption if gypsy moth defoliation is to be mapped, these costs are comparable.

Photo interpretation time including annotation, classification and map transfer required approximately 100 person hours for the test site. Photo acquisition and interpretation are compared to costs of aerial sketchmapping over the same area (Table 5). These data indicate that the aerial photo survey is higher than a conventional sketchmap survey with a ratio of 1.7 to 1 (photo vs. sketchmap).

An additional cost comparison that can be made is to compare cost of panoramic aerial photo acquisition with that of large to medium scale nine-inch aerial photography. Photo acquisition costs, exclusive of ferry time for a USDA Forest Service photo aircraft, are $14.16 per mi^2 for 1:8,000 scale photography and $7.00 per mi^2 for 1:24,000 scale photography. These photo scales are reasonable alternatives because 1:8,000 is

TABLE 4. Analysis of agreement between aerial sketchmapping and photo interpretation of Gypsy Moth defoliation by photo interpreter - Central Pennsylvania - 1981.

Photo Interpreter	Z Statistic by Frame Segment	
	Nadir to ± 20°	± 20° to ± 40°
1 vs 2	1.68 n.s.	1.25 n.s.
1 vs 3	4.50**	6.33**
2 vs 3	6.08**	4.24**

n.s. - $K_1 = K_2$

** - $K_1 \neq K_2$ ($p = .01$)

TABLE 5. Cost comparison of aerial sketchmapping vs panoramic aerial photography for mapping Gypsy Moth defoliation in Central Pennsylvania - 1981.

Aerial Sketchmapping[1/]		Panoramic Aerial Photography	
Aerial observers	$ 865.68	Photo acquisition	$6,384.00
Flight preparation	1,465.45	(2800 mi^2 @ 2.28/mi^2)	
Aircraft rental	2,151.82	Photo interpretation	1,172.00
Map cost	82.50	100 hrs. @ $11.72/hr	
		Map cost	82.50
	$ 4,565.45		$7,638.50

[1/] Data Source - letter from John W. Quimby, Commonwealth of Pennsylvania, Bureau of Forestry, Division of Forest Pest Management to Robert Acciavatti dated January 25, 1982.

generally regarded as the operational photo scale for mapping pest damage and 1:24,000 is the current standard photo scale for resource aerial photography in USDA Forest Service.

A photo scale of 1:24,000 is undoubtedly quite satisfactory for accurate mapping of vegetation damage of the extent and intensity typical of a hardwood defoliation such as the gypsy moth. Acquisition of photography at this scale costs approximately three times that of optical bar photography. In addition, photo interpretation costs could be expected to increase because of the greater number of aerial photographs that would have to be handled.

Availability of panoramic aerial photography may provide an opportunity to measure foliage protection in areas treated for gypsy moth suppression. Medium scale color and color IR photos have been shown to be effective for assessing quality of aerial applications of pesticides (Ciesla et al. 1971). These have been used successfully to evaluate field experiments of promising insecticides against the gypsy moth (White et al. 1978).

Post suppression evaluation of areas treated for gypsy moth suppression are presently done on a limited basis by air and ground evaluation and include only a small proportion of areas actually treated. If this task can be done for all areas treated simultaneously with defoliation mapping, it will increase the overall cost-effectiveness of the photo acquisition because two products, a map of defoliation and an assessment of foliage protection in treated areas could be obtained from a single photo mission. The latter product is presently not obtained.

We plan to study the feasibility of measuring foliage protection in the near future using the data from this test site. Results will be issued separately.

CONCLUSION

We conclude that panoramic aerial photography is a cost effective tool for improved mapping of gypsy moth defoliation. Photo interpreters familiar with vegetation damage and gypsy moth can effectively map defoliation within $\pm$ 40° of nadir provided that aerial photography is acquired at time of peak gypsy moth defoliation. Panoramic aerial photography provides a permanent record of defoliation and may provide the opportunity to evaluate foliage protection due to aerial application of pesticides for gypsy moth suppression.

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